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TERNARY SYSTEM: ALUMINUM - MAGNESIUM - LITHIUMPART II. MICROPHOTOGRAPHS

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[Figures referred to herein are appended.]

We studied the constitution diagram of ternary system Al-Mg-Li by thermic analysis for the case of constant Li, and variable Al and Mg, and by microphotographs structure. In addition to variable Al and Mg, we studied two composition ranges between points Al_3Mg_4 - $AlLi$ and $Al - Mg_2Li$ on the constitution diagram. Beside thermic analysis and microstructure, we studied hardness, conductivity, and several other properties. To provide a basis for the particular conclusions reached as to system Al-Mg-Li, we shall begin with a short description of "cross sections" (the term we shall use for compositions varying in Al and Mg and constant in Li, as indicated on a constitution diagram).

Cross Section With 5 Atomic Percent Li

Data on the thermic analysis of this cross section is graphically represented in Figure 1. It is evident from the diagram that a vertical plane parallel to Al-Mg for the case of 5 atomic percent Li intersects three regions of initial crystallization and forms with the surface a liquidus of three branches: AB, BCD, and DE. On branch AB, crystallization occurs in phase V (a ternary solid solution of Al and Li in Mg). On branch BCD, it is phase IV (a ternary solid solution of compound Al_3Mg_4 with Li and its remaining components), and on branch DE it is phase I (a ternary solid solution of Mg and Li in Al). Phase I, I with its own region of initial crystallization has no bearing on the study of mixture.

- 1 -

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50X1-HUM

To study the microstructure of this composition, specimens were prepared at 1 - 2 percent and after suitable thermal processing were analyzed under a metal microscope. Such research established that, at 425° and high temperatures, alloys in the central part comprised only two phases: phase II corresponding to the beta-phase of binary system Al-Mg, and phase IV (a ternary solid solution of compound Al_2Mg_3 with Li and the remaining components of this compound). When cooled to room temperature, the alloys likewise comprised only these two phases. Alloys quenched at 390° revealed a third phase (III) in addition to the phases mentioned. As the data from thermic analysis does not bring out this phase and, furthermore, as it is not among the alloys quenched at 425° or among the tempered alloys, it is obviously formed in the solid state of phase IV and disappears with decrease in temperature.

Photographs 1, 2, and 3 represent the microstructure of heterogeneous alloys with the initial precipitation of a solid aluminum solution. Photographs 4 and 5 show the microstructure of a solid solution corresponding to the beta-phase of binary system Al-Mg. Photographs 6, 7, and 8 again show the heterogeneous structure of a mixture of phases IV + III. Photographs 9 to 13 show the structure of phase IV of the ternary solid solution forming the compound Al_2Mg_3 with Li and remaining components. All these are structures of tempered alloys. Photographs 14 to 19 show the microstructure of alloys of this section quenched at 420°.

Cross Sections With 10 and 15 Atomic Percent Li

Constitution diagrams of these cross sections are given in Figure 2. It is clear from the diagrams, that the cross section with 10 atomic percent Li is not new in principle as compared with the foregoing cross section.

In the constitution diagram, the vertical plane, cutting the spatial temperature "model" of the ternary system parallel to Al-Mg with 10 atomic percent Li, passes in the central part through the same three regions of initial crystallization as did the cross section with 5 atomic percent Li, with the sole difference that the region of ternary solutions of compound Al_2Mg_3 is comparatively narrower in this cross section, and somewhat out of line with the side toward the binary system Al-Li as may be seen from Figure 3. The cross section with 15 atomic percent Li passes through the same three regions of initial crystallization as the first two. However, this cross section already indicates that there is in ternary system Al-Mg-Li, beside the combinations peculiar to secondary systems, a peculiar compound of its own inherent in ternary systems alone. In fact, during the period of joint crystallization along the boundary line of phases I and II, when the temperature drops to 502°, phase II due to interaction with the liquid matrix produces phase X, a new chemical compound, and disappears itself. The disappearance of phase II is also characteristic of a cross section with 15 atomic percent Li.

Photographs 20 to 27 show the microstructures of tempered alloys in the central part of a cross section with 10 atomic percent Li. The study of microstructure afforded sufficiently convincing proof that these alloys have two phases, IV and II. For alloys quenched at 375°, another alloy with 40 percent Mg seemed to have a monophase. The microstructure of alloys quenched at 325° (photographs 28 to 35) again indicated the existence of only one phase. Photographs 36 and 37 show the typical diphasic structures of this section. The microstructure of alloys in the section with 15 atomic percent Li is shown in photographs 38 to 41 for a quenched temperature of 370°.

Thus, a comparative study of microstructures and of the data of thermic analysis of cross sections with 10 and 15 atomic percent Li demonstrates that the phases II, III, and IV enter by means of long narrow wedges, deep into the prism of the ternary system, and the presence of phases II and III can also be

- 2 -

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50X1-HUM

affirmed in cross sections with 15 atomic percent Li. It is true that in cross sections with 15 atomic percent Li, we did not succeed with the aid of micro-photographs in adducing very convincing arguments for the presence of phase III. But we had generally little luck with the microstructure of this cross section. The alloys have proved exceptionally friable, and despite every effort, we did not succeed in obtaining good specimens to show the presence of this phase.

Cross Sections With 20 and 30 Atomic Percent Li

Thermic-analysis data on these cross sections are represented by graphs in Figures 4 and 5. The principal interest in cross sections with 20 atomic percent Li is the complete absence of the range of solid solutions in the central part of the constitution diagrams of the two previous cross sections, and the existence of a fourth branch of the curve of the intersection of liquidus surface with the vertical plane, passing through 20 atomic percent Li, parallel to Al-Mg. On branch AB in this cross section, crystallization occurs in phase V a ternary solid solution of a compound of Al and Li in Mg, and on branch BC, a solid ternary solution of the compound Al_2Mg_3 with Li and remaining components. On branch CD, crystallization first occurs in the ternary intermetallic chemical compound discovered by us, namely phase X. On branch DE, a phase (I) of a ternary solid solution of Mg and Li in Al is crystallized first.

The cross section with 30 atomic percent of Li again forms with the liquidus surface a curve consisting of only three branches, namely AB, BC, and CD. Corresponding to branch AB in this cross section is the initial crystallization of phase VI, a ternary intermetallic compound. On branch CE, crystallization occurs in phase IX. In regard to the absence of solid solutions in the central part of this cross section, study of the microstructure is of interest only from the standpoint of binary system Mg-Li. Photographs 42 and 43 show the boundaries of ternary solid solutions formed by the combination of Mg_2Li with Al and remaining components.

Cross Sections With 50 and 60 Atomic Percent Li

Cross sections with 50 and 60 atomic percent Li are much simpler than the foregoing ones. The former (Figure 6) is a typical quasi-binary cross section. It passes through two regions of initial crystallization. On branch AB, a ternary solid solution is isolated on the base of a Mg_2Li compound, and on branch BC, phase IX. A cross section with 60 atomic percent Li (Figure 7) forms a liquidus curve which is also composed of two branches. The initial crystallization of phase VI corresponds with branch AB. Phase IX is isolated on branch BC.

Cross Sections Al_2Mg_3 - $AlLi$ and Al - Mg_2Li

Data from thermic analysis of cross sections, parallel to Al-Mg are represented by graphs in Figures 8 and 9. The cross section Al_2Mg_3 - $AlLi$ proved to be of special importance in solving the problem of the constitution diagram of system Al-Mg-Li. At the intersection with the liquidus surface, this cross section shows a curve consisting of three branches AB, BC, and CD. The phase of initial crystallization proper to its branch corresponds to each of these branches. Phase IX, a ternary solid solution of the compound $AlLi$ with Mg and remaining components of the compound, is isolated on branch CD. When the temperature drops to the point C, phase IX sets up an interaction with the liquid alloy, and by peritectic reaction at temperature 527° forms a new phase X. At this temperature, there is equilibrium: liquid + phase X, IX. Hence, in accordance with the phase rule $F = n+1-4 = 2+1-3 = 0$ the temperature cannot be changed so long as phase IX does not disappear in cooling or phase X, in heating. An initial isolation of the new phase X occurs on branch CB since the phase is already stable at the temperatures corresponding to this branch. When a temperature of 477° is reached, phase X in turn sets up an interaction with the liquid melt and produces phase IV.

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A question now arises: On the base of what ternary intermetallic compound is phase X formed? It may be assumed with the highest degree of probability that this phase is formed on the base of the ternary intermetallic compound Al_2MgLi , melting and dissolving at 527° , since the region of its occurrence is very close to the point corresponding to 50 atomic percent, 25 percent Mg and 25 percent Li. From the constitution diagram of this section, it is clear that phase IV occurs at 20 atomic percent Li. Thus, the data obtained for this section confirm the results obtained on the basis of cross sections parallel to Al-Mg. In regard to this cross section, it should be noted that, as a result of the loss in lithium, it proves to have a slight displacement toward the Al_2Mg side, and does not lie strictly in the section $\text{Al}_2\text{Mg}_4\text{-AlLi}$.

In regard to the cross section $\text{Al-Mg}_2\text{Li}$, it is clear from figure 9 that this cross section intersects the liquidus surface on a curve composed of four branches. As we might expect from the given cross sections parallel to Al-Mg, phase VI is crystallized first on branch AB, and phase X, on branch BC. Branch CD is responsible for the isolation of phase IV, and phase I is isolated on branch DE. Thus, this cross section also confirms the data acquired on the basis of cross sections parallel to Al-Mg.

On the basis of the above data from thermic analysis and microstructure, we have made constitution diagrams of system Al-Mg-Li. A statement of the problem of constructing a constitution diagram of ternary system Al-Mg-Li will be made in a subsequent report.

Conclusions

As a result of our research work on cross sections of system Al-Mg-Li, it has been established that cross sections with 5 and 10 atomic percent Li have a great similarity to the constitution diagram of binary system Al-Mg. Cross sections with 15, 20, and 20 atomic percent Li indicate the presence in the ternary system of its own ternary intermetallic compound, peculiar to this system only. A cross section with 50 atomic percent Li is a simple binary system with two branches of a liquidus curve passing through two fields of initial isolation. A cross section with 60 atomic percent Li likewise comprises only two branches. The data from thermic analysis in research were confirmed by a study of the structure of the alloys.

The results of studying the system by cross sections, parallel to the Al-Mg side, were confirmed by the study of cross sections: $\text{Al}_2\text{Mg}_4\text{-AlLi}$ and $\text{Al-Mg}_2\text{Li}$.

[Forty-one photographs of alloy structure are not reproduced.]

[Appended figures follow.]

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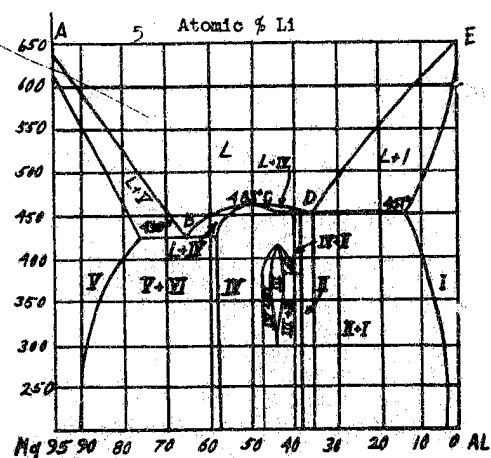


Figure 1. Constitution Diagram of Alloys of System Al-Mg-Li in Cross Section With 5 Atomic Percent Li

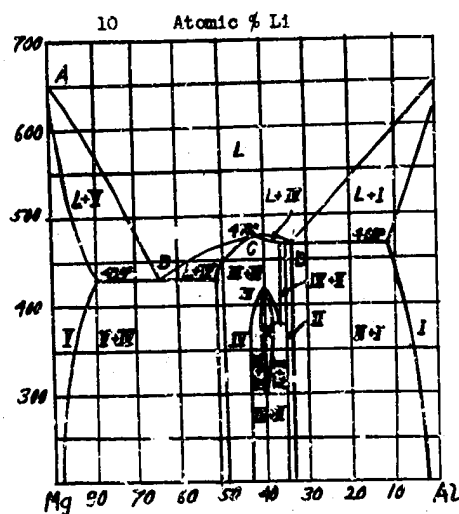
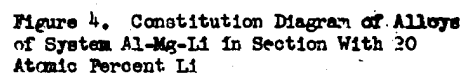
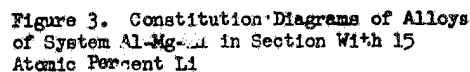


Figure 2. Diagram of Alloys of System Al-Mg-Li With 10 Atomic Percent Li

- 5 -

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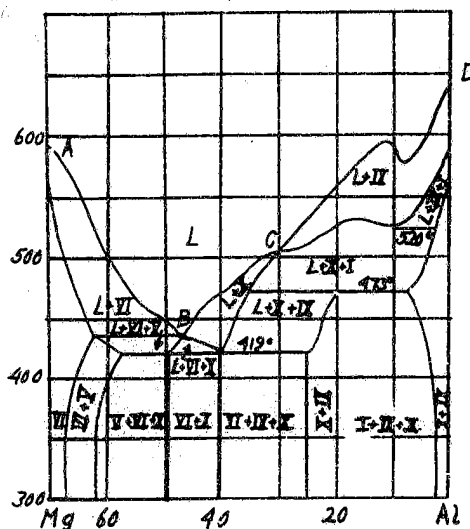
15 Atomic % Li



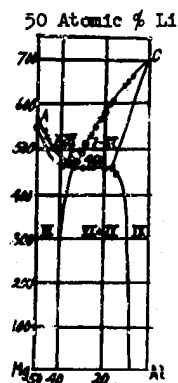
- 6 -

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30 Atomic % Li



60 Atomic % Li



- 7 -

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